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Network design model for intermodal transport: the case of the hinterland of the Port of Cotonou

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Abstract : *Since 2006, the Millennium Challenge Account program subsidizes a project to improve the performance of the Port of Cotonou, through modernization of infrastructure and management systems, and strengthening institutional reforms. But the project mainly concerns the port, not the development of its hinterland. However, no port can develop without its links with its hinterland. That's why we analyse the issues relating to the hinterland transport network. Both rail and road transportation networks will be examined. We also investigate inland terminals in order to build up intermodal transportation which is almost non-operational. Thus, the objective of this paper is to determine the optimal number and locations of the terminals so that the total costs of the distribution network are minimized.*

Keywords : *Intermodal transport, hinterland, port of Cotonou*

1 Introduction

Republic of Benin has been eligible since 2006 for five years of the Millennium Challenge Account Program (MCAP). This subsidy agreement of approximately U.S. $ 307 million aims at increasing investment and the private sector activities in Benin. This program consists of four projects namely: Access to Land, Access to Financial Services, Access to Justice and finally Market Access. On the other side, the neighbouring ports of the Port of Cotonou (Lome, Tema, and Abidjan) have not benefited from such investment project.

The first project, the Market Access, represents 55.14% of the subsidies of MCAP. It aims at improving performance of the Port of Cotonou through modernisation of infrastructure and management systems and, strengthening institutional reforms in order to make it one of the most competitive ports in West Africa.

But the project mainly concerns the port, not the development of its hinterland. However, no port can develop without links with its hinterland. Our main purpose is to determine how to optimise the expected growth of flows to and from hinterland countries in order to avoid congestion in this port, increase its market share and make economies of scale, in short increase its performance.

Hence, the objective of this research is to analyze the issues related to the hinterland of the port of Cotonou and to improve freight transportation network in this region. The remainder of this paper is organised as follows: the next section highlights the development of the hinterland of the port of Cotonou. Section 3 contains the description of our mathematical model while section 4 presents and analyses the obtained intermodal transportation for the hinterland of the port of Cotonou. The section 5 states for conclusion and discussion.

2 Ports hinterlands

The development of global trade deeply changed the relationship between the points on networks such as ports and their areas of influence. Interdependence between seaport gateways and their hinterlands is a first principle which supports seaport development, Charlier (1983). A few key factors have facilitated the rise of gateways competing for contestable hinterlands (Hoyle (1988); Ferrari et al. (2011)). It becomes difficult to draw the hinterland's shape as its extension can largely vary with respect to commodity (Blauwens and Van de Voorde (1988)) and transport mode.

2.1 Hinterland's importance

In our knowledge, the first analysis of port hinterlands is provided by Sargent (1938), followed by Morgan (1951) who shows that the hinterland of a port is different for each commodity. Taaffe et al. (1963) have analysed increasing concentration of transport flows on a few corridors to the hinterland. They propose model for hinterland connections development enhanced by Hoyle (1983). Moreover Bird (1963) describes spatial change of port complexes and Van Klink (1995) stresses that ports increasingly create networks with hinterland nodes to enhance the competitive position. Rodrigue (2004) emphasise the importance of corridors to the hinterland. Thus, Notteboom and Rodrigue (2004) introduce the concept of island formations that can give a port a competitive edge in a hinterland. De Langen and Chouly (2004) point out the importance of analysing hinterland access as an interorganisational issue.

The development of containerisation and intermodality expands land penetration of maritime containers by creating landbridges. Hoyle (1988) and, Hoyle and Charlier (1995) have discussed some of the complexities of hinterland topology, and concluded that the idea of the hinterland no longer has any relevance in advanced societies and in context of intermodalism. Thus, hinterlands which were captive and natural are shared and contestable; also the perception on port markets has changed from being monopolistic or oligopolistic to competitive.

Hence, conventional perspectives based on distance-decay are ill-fitted to address this new reality. In this respect, a fundamental role is played by the effectiveness of inland connections (Ferrari et al. (2011)). And then, Ferrari et al. (2011) discuss the gravitational forces and frictions, and reshaping port hinterland to emphasis the explanatory power of distance in defining ports hinterlands. Debrie and Guerrero (2008) support this trend while some authors assert that the hard competitive game among the top players defines a hinterland as a spatial job, in which the port choice is not necessarily related to the inland distance (Notteboom (1997); Olivier and Slack (2005)). Therefore, the distance would seem to have become only one of the different parameters that contribute to determine the share of the inland market of a port. Morgan (1951) and De Langen (2007) make a difference between captive and contestable hinterlands and show that contestable hinterlands exist in regions where no single port has a clear cost advantage over competing ports. Addressing the Lugirian case of port hinterland accessibility, Ferrari et al. (2011) show that a crucial factor in inter-port competition turned out to be the penetration capacity in hinterland and that inland terminals have an important role in enlarging port market areas, as their strategic location may represent an attractive gravitational factor, reducing the frictions generated by the distance.

2.2 Hinterland development for the port of Cotonou

Inter-port competition closely explains ports hinterland development, that why many authors address this issue. Hoyle and Charlier (1995) studying the inter-port competition in East Africa by using ports traffic volumes, highlight little competition between the two major ports of the region (Mombasa and Dar es Salaam), but argue that the real competition is further inland. They stress that intermodalism has become a key issue in hinterland competition (see also Janguo (1994) and Mumba (1994)). This findings are consistent with Ferrari et al. (2011) who address Lugirian port hinterland accessibility and show that inland terminals confirm their primary role in enlarging port market areas, as their strategic location may represent an attractive gravitational factor, reducing the frictions generated by the distance (see Feo-Valero et al. (2011) for the importance of inland leg). Furthermore, Huybrechts et al. (2002) assume that strategic positioning is an instrument for port competition analysis.
However, in West Africa, ports still protect their captive hinterlands. The competition is not yet hard. Hence, port-hinterland relations and port concept retain considerable relevance (Hoyle and Charlier (1995); Charlier and Tossa (1995)). Indeed, the natural gateway of Niger is the port of Cotonou, so all its oil and mining traffic, and the most general cargoes traffics use this transit route. This landlocked country (LLDC) is becoming increasingly important for the port of Cotonou. Indeed, its annual population growth is quite high with a rate of about 3.5% in 2010 (Banque Mondiale (2010); INS Niger (2010)), then sustained increase in imports to meet the needs of its population of about 15.5 million (Banque Mondiale (2010); INS Niger (2010)) and its high mining area potential could increase exports.

Burkina-Faso shares its oil traffic between the ports of Cotonou (small share) and Abidjan (most important). Since the political instability of Côte d'Ivoire, the balance of its traffic, is mainly shared between the ports of Lome and Tema. The traffic of Mali uses the ports of Abidjan, San Pedro, Takoradi and at a very less extent the port of Cotonou. Furthermore, the port of Cotonou has good opportunities with its neighbour robust economic growth since year 2009. Indeed, Nigeria has good economic outlook for the future, despite the global economic crisis (BAD OCDE PNUD CEA (2010)). But weaknesses occur and are related to the permanent congestion and the inefficiency of its ports, the growing insecurity and, language and currency problems. So, the port of Cotonou is the transit port of Nigeria and this position should improve with the MCAP. However, inter-port competition becomes increasingly important even whether it's not reached the developed countries stage (see Hoyle and Charlier (1995); Charlier and Tossa (1995)), changing the port hinterland relationships and making a new market share. Port hinterlands move gradually from captive to contestable position, that's why

inter-port competition has to be addressed.
To address inter-port competition in our study, total and transit traffic are compared from 2004 to 2008 for the four ports (Abidjan, Cotonou, Lome and Tema). We choice this time window because of the availability of data for all the ports studied. Data are gathered from ports statistics on their websites and triangulated with LLDCs Shippers Council's data. However, as we know that currently for oil and used cars, some ports have natural advantage; the net total traffic, without oil and cars, is given in Table 1 while transit traffic is given Table 2. Transit traffic is the traffic through the port from or to other country, in our case, hinterland countries. As it can be seen in the two tables below, Abidjan has high volume for total traffic while Cotonou has high volume for transit traffic.

Year	2004	2005	2006	2007	2008
Cotonou	3 969	5 153	5 369	6 152	6 998
Lome	3 299	3 452	3 531	4 429	4 937
Tema	11 288	12 637	11 371	8 868	9 182
Abidjan	17 770	18 662	18 856	21 378	22 080

Table 1: Ports total traffic in 1000 tons (2004-2008)
Source: Ports statistics

Year	2004	2005	2006	2007	2008
Tema	764	875	870	844	866
Abidjan	530	762	1 002	1 278	1 016
Lome	1 095	1 221	1 394	1 862	2 093
Cotonou	1 242	2 041	2 474	2 849	3 414

Table 2: Ports transit traffic in 1000 tons (2004-2008)
Source: Ports statistics

These outcomes show the strong position of the port of Abidjan in region, as the leader. His challenger is Tema while Cotonou is more competitive than Lome. Hence, this port might be ranked first by the port users (freight forwarders and shippers). However, considering transit traffic, we could note that Cotonou ranked first followed by Lome. We can conclude that Cotonou and Lome are both transit ports, and Cotonou is first for hinterland market share attraction, where it has a dominant position. This strategic position is enforced by its Nigerian transit traffic with no, or at least, very weak competition. Future studies will evaluate the reliability of these results. Furthermore, as intermodal has become a key issue in hinterland competition (Hoyle and Charlier (1995)), it seems necessary to know how hinterland network service is designed.

3 Model

According to the European Conference of Ministers of Transport, ECMT (1997), intermodal freight transport is defined as the movement of goods in one and the same loading unit or vehicle by successive modes of transport without handling of the goods themselves when changing modes. Many theories are mobilized to give better understanding of intermodal transportation (see Crainic and Kim (2007) for review). The key objectives of intermodal freight transportation are both to minimize total transportation costs and enhance sustainable transportation through modal shift from road to rail, waterways or short sea shipping (see Notteboom (2010)). To create a rail-road intermodal network for the hinterland of a port, we have to find optimal locations for terminals according to the existing rail and road network and according to the flows from and to this port. The first model is based on the one developed in Arnold et al. (2001).

In this study, a set of commodities, A, may be shipped from their origin h (Port) to their destinations $i \in N$ either directly or via a consolidation terminal $k \in T$. A set of commodities, E, have also to be moved from node $i \in N$ to the port. The main decisions addressed by the models are the number and the locations of consolidation terminals as well as the product flow pattern through the system, either directly from the origin to destination by road or through a consolidation terminal, i.e. rail-road transport. The problem can be stated as follow:

3.1 Input

- n the number of sites for potential terminals indexed by k, $k \in T$
- p the number of terminal to locate
- N the set of nodes to which is associated a flow from or to the Port
- A the set of commodities to be moved from the port to the destinations (import)
- E the set of commodities to be moved from the destinations to the port (export)
- c_{ij}^{1a} road transportation cost per ton of commodity received $a \in A$, $i \in N \cup T \cup \{h\}$ and $j \in N \cup T$
- c_{ij}^{1e} road transportation cost per ton of commodity sent $e \in E$, $i \in N \cup T$ and $j \in N \cup T \cup \{h\}$
- c_{ij}^{2a} rail transportation cost per ton of commodity received $a \in A$, $i \in T \cup \{h\}$ and $j \in T$
- c_{ij}^{2e} rail transportation cost per ton of commodity sent $e \in E$, $i \in T$ and $j \in T \cup \{h\}$
- t^{1a} trans-hipment cost from sea to road per ton of commodity received $a \in A$
- t^{2a} trans-hipment cost from sea to rail per ton of commodity received $a \in A$
- t_k^a trans-hipment cost from rail to road per ton of commodity received $a \in A$ in the terminal $k \in T$
- t^{1e} trans-hipment cost from road to sea per ton of commodity sent $e \in E$
- t^{2e} trans-hipment cost from rail to sea per ton of commodity sent $e \in E$
- t_k^e trans-hipment cost from road to rail per ton of commodity sent $e \in E$ in the terminal $k \in T$

u_k the capacity of a consolidation terminal located at site $k \in T$

d_i^a total quantity in ton of commodity received $a \in A$ at the node $i \in N$

o_i^e total quantity in ton of commodity sent $e \in E$ from the node $i \in N$

3.2 Decision variables

Here are the different variables used in the model.

$$y_k = \begin{cases} 1 & \text{if a terminal is located at node } k \in T \\ 0 & \text{otherwise.} \end{cases}$$

$$x_{ki}^a = \begin{cases} 1 & \text{if the flow of commodity } a \text{ from the Port to node } i \in N \text{ is trans-shipped in } k \in T \\ 0 & \text{otherwise.} \end{cases}$$

$$x_{ik}^e = \begin{cases} 1 & \text{if the flow of commodity } e \text{ from node } i \in N \text{ to the Port is trans-shipped in } k \in T \\ 0 & \text{otherwise.} \end{cases}$$

$$w_i^a = \begin{cases} 1 & \text{if the flow of commodity } a \text{ from the Port to node } i \in N \text{ is not trans-shipped} \\ 0 & \text{otherwise.} \end{cases}$$

$$w_i^e = \begin{cases} 1 & \text{if the flow of commodity } e \text{ from node } i \in N \text{ to the Port is not trans-shipped} \\ 0 & \text{otherwise.} \end{cases}$$

3.3 Objective function

The objective function consists in minimizing the total transportation cost.

$$\begin{aligned} minimise \sum_{i\in N}\sum_{k\in T}(\sum_{a\in A} d_i^a(t^{2a} + c_k^{2a} + t_k^a + c_{ki}^{1a})x_{ki}^a) \\ + \sum_{e\in E}(o_i^e(t^{2e} + c_{ik}^{1e} + t_k^e + c_{kh}^{2e})x_{ik}^e)) \\ + \sum_{i\in N}(\sum_{a\in A} d_i^a(t^{1a} + c_{hi}^{1a})w_i^a \\ + \sum_{e\in E} o_i^e(t^{1e} + c_{ih}^{1e})w_i^e) \end{aligned} \tag{1}$$

3.4 Constraints

$$\sum_{k\in T} y_k = p \tag{2}$$
$$w_i^a + \sum_{k\in T} x_{ki}^a = 1 \quad \forall a \in A, \forall i \in N \tag{3}$$
$$w_i^e + \sum_{k\in T} x_{ik}^e = 1 \quad \forall e \in E, \forall i \in N \tag{4}$$
$$x_{ki}^a \le y_k \quad \forall a \in A, \forall i \in N, \forall k \in T \tag{5}$$
$$x_{ik}^e \le y_k \quad \forall a \in A, \forall i \in N, \forall k \in T \tag{6}$$
$$\sum_{i\in N}\sum_{a\in A} d_i^a x_{ki}^a + \sum_{i\in N}\sum_{e\in E} o_i^e x_{ik}^e \le u_k y_k \quad \forall k \in T \tag{7}$$
$$y_k \in \{0,1\} \quad \forall k \in T \tag{8}$$
$$w_i^a \in \{0,1\} \quad \forall a \in A, \forall i \in N \tag{9}$$
$$w_i^e \in \{0,1\} \quad \forall e \in E, \forall i \in N \tag{10}$$
$$x_{ki}^a \in \{0,1\} \quad \forall a \in A, \forall k \in T, \forall i \in N \tag{11}$$
$$x_{ik}^e \in \{0,1\} \quad \forall\forall e \in E, k \in T, \forall i \in N \tag{12}$$

The objective function minimizes the total transportation cost associated of distributing the commodities flows from and to the port and opening the consolidation centres. Constraint (2) denotes that p terminals are going to be located. The constraints (4) and (3) ensure that all the demand is satisfied while constraints (6) and (5) indicate that a trans-shipment is not possible, unless there is a terminal. Constraint (7) enforces the consolidation-terminal capacity constraint. Finally, constraints (8) to (12) standard non-negativity and integrality constraints.

4 Intermodal transportation network for the hinterland of the port of Cotonou

A real-world data set is provided from the port of Cotonou statistics. We use the data concerning the total quantities of goods transported from and to the port (imports and exports). The countries considered are Benin, Burkina-Faso, Mali, Niger and Nigeria. The origin-destination (O-D) matrixes are built up for the year 2010.

On one hand, the main categories of commodities sent are wood; cotton; others products and uranium; cottonseed; hydrocarbons and liquid bulk; cashew nuts; shea nuts; perishable products; cakes; various goods. On the other hand, the main categories of commodities received by the hinterland of the port of Cotonou are: grains, clinker, gypsum, limestone and slag; fertilizers and insecticides; hydrocarbons; lubricants and bitumen; building materials; equipment; food; sulfur; vehicles and parts; various goods.

To test our model, we aggregate the various commodities. The estimations of the transport and operations costs used are those from Limbourg and Jourquin (2009) based on the RECORDIT (2002) European research program, which compared the costs of intermodal and road-only solutions. Knowing that the average net weight of a twenty-foot equivalent unit (TEU) is about 15 t and container traffic statistics of the port of Cotonou for the year 2010, the (un)loading costs are estimated to 1.297 /t for all the different types of trans-shippment, the cost for road haulage is 0.072 /t.km and 0.042 /t.km for rail haulage. Future research will tackle the issue related to the estimation of real transport and operations costs for the main kinds of commodities of the previous paragraph.

Rail stations are considered as potential locations for terminals. They are located in Bohicon, Dassa, Parakou and Savè. Knowing all the input, the model is solved using the classical branch-and-cut CPLEX12 solver with the default parameters. Moreover, for each located terminal, we compute its market area which is the area where the intermodal transport passing through the terminal considered is cheaper than road transport or than an intermodal transport using another terminal.

If one terminal ($p = 1$) has to be opened, it should be located in Parakou, its market area, include Burkina-Faso, Mali, Niger and the blue area represented in Figure 1.
If two terminals ($p = 2$) have to be opened, they should be

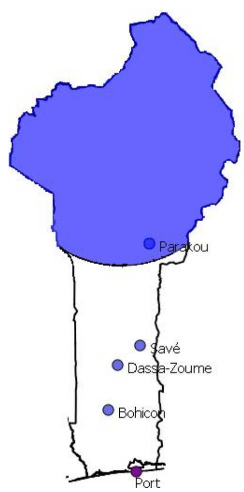

Figure 1: Configuration with one terminal

located in Parakou and in Dassa. In this case, a part of the market area of the terminal located in Parakou is cannibalized by the market area of Dassa, represented in red (Figure 2). If three terminals ($p = 3$) have to be opened, they should be located in Parakou, Dassa and Bohicon which has a very little market area represented in yellow (Figure 2). The total transportation cost can't be reduced by adding another terminal.

The total cost decreases when the number of terminals increases. This is true when p varies between zero to three. But, only the reduction due to the terminal located in Parakou is significant according to our assumptions. This result is consistent with the MCAP which projects to build up a dry port at Parakou. However, this result must be refined by taking into account the actual transportation costs in West Africa, the variation of transportation costs according to the type of commodity transported, the management of hazardous and perishable goods.

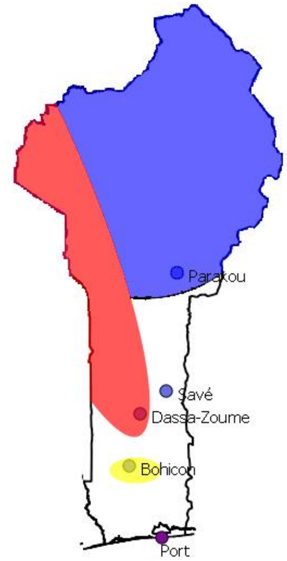

Figure 2: Configuration with three terminals

Moreover, our model allows us to compute the variation of the ton-km transported by road for all these configurations, to assess the environmental impact and to compute the number of container trans-shipped at each terminal. These are usefull indicators for the policy makers and for the operators. For example, the former indicator helps to determine the terminal design as well as the number and type of cranes needed.

Furthermore, a large railway interconnection network project has to link ECOWAS (Economic COmmunity of West African States) Countries with two railway major bands cross these countries, one coastal and the other Sahelian. Thus, rail lines from ports to inland link the above two bands, insuring West African countries interconnection. Our model should also be test in this case, where more potential locations for terminals have to be considered.

5 Conclusion

The main objective of our research is to find out how the port of Cotonou can achieve and maintain its competitive advantage in transit traffic with hinterland countries. Because high hinterland connectivity improves the competitive position of port and because intermodal transportation generates significant advantages such as sustainability, our research focus on the intermodal transportation network design for the hinterland of the Port of Cotonou. Therefore, a multi-product model has been formulated to find optimal locations for rail-road terminals.

Secondly, the obtained results shows that only one terminal should to be located. However, we have to find more accurate data about transportation costs in West Africa for each considered commodity to provide a decision support system to port authorities and operators.

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